AVISTA Labs

Final Project Report for Geiger Field Installation

Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities

242nd Combat Communications Squadron, Geiger Field, WA

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Introduction

Background

The Construction Engineering Research Laboratory (CERL) is a division of the U.S Army Engineer Research and Development Center. CERL's mission is to assist the military in addressing existing needs, directing research, and developing products utilizing experimental technologies. The Residential Fuel Cell Program is intended to advance the development of PEM fuel cells and promote their penetration into the marketplace by providing long-term test data to Department of Defense personnel as well as fuel cell manufacturers.

The Avista Labs SR-72 modular Proton Exchange Membrane (PEM) fuel cell was a 3kW fuel cell utilizing Avista Labs' modular cartridge technology. The scope of the project was to install an SR-72 at the Geiger Field, 242nd Combat Communications Squadron's building 401. The mission of the fuel cell was to power lighting at the installation, large bay doors, and the building's Local Area Network (LAN) switch. The objective of the test was to run for a period of one year with 90% availability to the load. The one-year test was completed on March 29th, 2003. The SR-72 exceeded the 90% availability requirement, meeting the load 93.24% of the time.

This report details the installation, operation and removal of the Avista Labs SR-72 fuel cell, as well as lessons learned throughout the course of the one-year test at Geiger Field.

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Installation Process

The 242 Combat Communications Squadron is a division of the Washington State Air National Guard. The squadron is located in Spokane, Washington at the south end of Spokane International Airport. The fuel cell was located in Building 401 of the Power Production Group of the 242nd. Building 401 serves as a maintenance shop for the 242's generators and portable air conditioners. The installation was completed in early March, 2002. Several installation standards and guidelines were utilized during the installation, see Appendix A, Table 2.

Site Selection

Site selection began in July 2001. Discussions with the Air National Guard resulted in selection of the Geiger Field facility. The Air National Guard recommended powering a load in building 401, their generator maintenance facility. A tour of the facility resulted in the decision to power a portion of the garage bay lighting, the building LAN switch, and garage bay doors. The lighting would provide a constant load (approximately 1.7 kW) for 10 hours a day, 4 days a week while personnel were on site. The large bay doors would provide a transient load at various times throughout the day. Powering the building's LAN switch would illustrate the role of PEM fuel cells as a reliable power source for mission critical equipment.

The bid for this project was awarded on October 4, 2001. Following this, Air Force personnel were contacted to obtain approval and establish chains of communication. Dr. Michael Binder, Fuel Cell Program Director visited the site December 17, 2001 for the project kickoff. Design then commenced on the project. The design was completed in mid-January, 2002 and the project was placed on hold pending approval from the Air Force and Air National Guard personnel. Both agencies approved the design and construction began in late January.

Site Layout

Figure 1 details the location of the fuel cell and the associated hydrogen fuel supply. The fuel cell was located in Building 401. The hydrogen supply (H2 STG., Figure 1) for the fuel cell was located on the north side of Bldg. 401, 50 feet from the building.

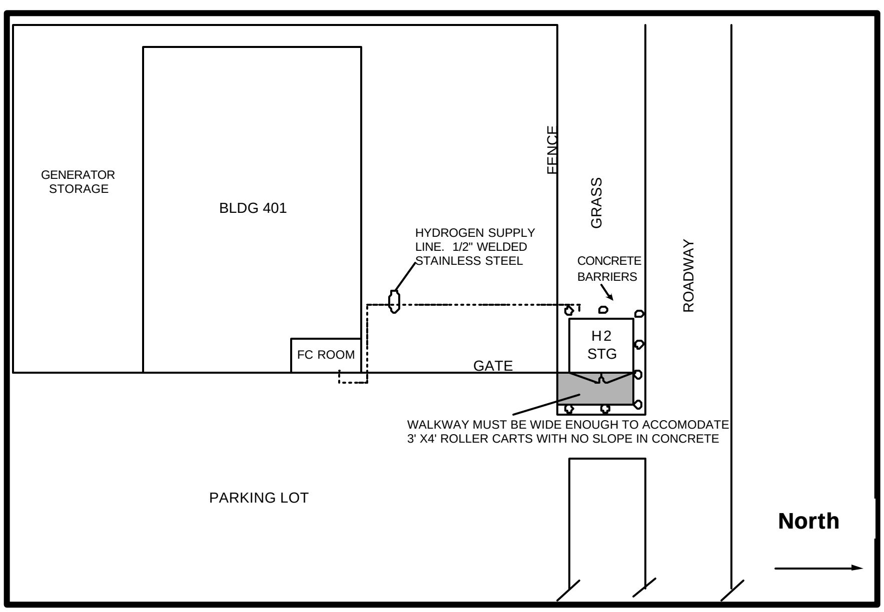

Figure 1

Room Layout

A storage closet in Building 401 was modified to serve as the fuel cell room. The fuel cell, a data-logging computer with associated sensors, power transfer equipment, and safety sensors were installed in the room. The data-logging computer and associated sensors were connected to the fuel cell for continuous monitoring and logging of data. The data-logging computer had access to an analog phone line. Test data was transferred to Avista Labs on a daily basis via a dial up modem.

Room Preparation

The fuel cell room previously served as a storage closet, a telecom room, and a compressor room. This room was renovated for the fuel cell installation. The compressor, the sink, and the air heater (Figure 3) were removed and the room refinished (Figure 4).

Figure 3

Figure 4

Room - Electrical

Once the maintenance equipment was removed from the fuel cell room and the room refinished, electrical modifications were made to the room. A disconnect switch, automatic transfer switch, distribution panel and UPS were all added to the room. The electrical one line is shown in Figure 5. The electrical work for the room, rewiring of the electrical circuits powered from the fuel cell, and the installation of the alarm systems were completed the latter part of February, see Figures 6 & 7. The electrical installation was compliant with NEC practices and complied with Article 692 of the NEC. Upon completion of the electrical work, the safety system was inspected and final approval was given on March 5, 2002. The fuel cell was installed on March 6, 2002.

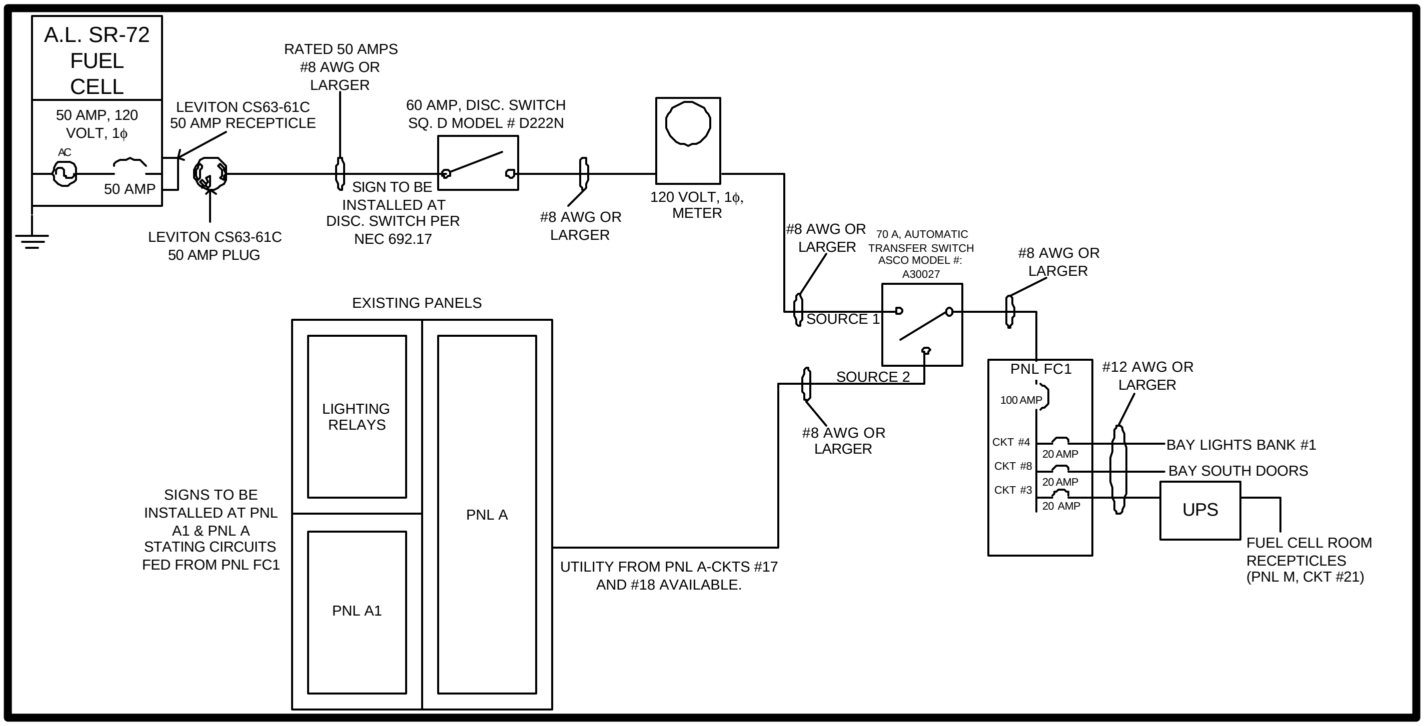

Figure 5

Figure 6

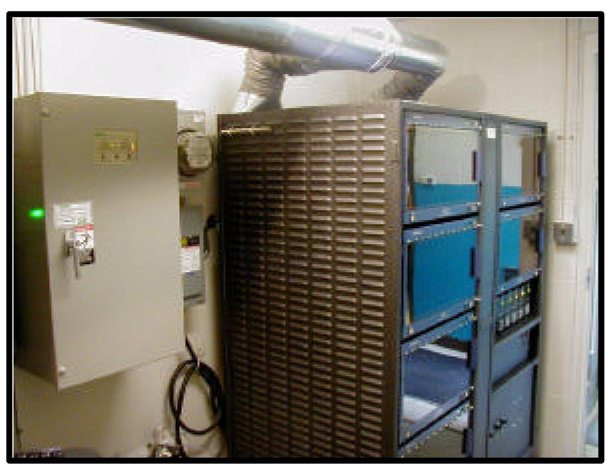

Figure 7

Hydrogen Distribution and Storage

Hydrogen Storage Shed

The hydrogen was housed in an open-air storage shed with chain link walls and a tin roof. An open-air structure was preferable to inhibit hydrogen buildup in the event of a leak. The site for the shelter was determined from NFPA 50A, as well as input from 242nd and Air Force personnel. The shelter was located approximately 50 feet to the north of building 401, Figure 8. Construction on the hydrogen storage shed began in January, 2002. Figure 9 shows the concrete pad and frame for the shelter. The shelter was completed by the end of January. The shelter measured 10 feet by 12 feet and utilized aluminum slats to limit visibility, Figure 10. Protecting the shelter were 3-foot high concrete piers spaced 4 feet apart. The shelter houses 4 hydrogen storage cradles. Each cradle consisted of 12 large, 261 CUF compressed hydrogen cylinders. Two cradles were joined together in a manifold to provide an uninterruptible supply of hydrogen. During full load conditions, each set of two hydrogen cylinders was changed out every 3 days averaging two exchanges a week.

Figure 8

Figure 9

Figure 10

Hydrogen System Piping

The hydrogen supplies were bussed together to provide 2 separate supplies of hydrogen consisting of 2 cradles. Each of these banks supplied the Avista Labs J-40 hydrogen module. The J-40 regulated the high pressure hydrogen to a distribution pressure (15 - 30 psi). It provided an automatic switchover regulator to allow transfer from one hydrogen supply to the other when a supply dropped below 200psi. Additionally, the J-40 incorporated several safety features including a velocity fuse, flashback arrestor, filter, check valve, and redundant safety solenoids. The J-40 was connected to ½" stainless steel piping. The piping was buried at a depth of 18 inches and ran from the J-40 to the wall of building 401, Figure 12.

In line with the hydrogen piping was a fireman's shutoff valve located on the exterior to the entrance to building 401. A manual shutoff valve and a low-pressure regulator were installed prior to connecting to the SR-72 hydrogen manifold inside the fuel cell room. The bleed line from the SR-72 was vented to the outside of the building using 3/16" stainless steel piping and the hydrogen was vented to atmosphere.

Figure 12

Hydrogen Supply Safety System

The hydrogen supply system incorporated several safety features. These features were necessary components of the CGA 5.4, 5.5 and NFPA standards, see Appendix A, Table 2. In addition to the J-40 hydrogen supply module safety features, the fuel cell room utilized a hydrogen sensor, a heat detector and an air flow velocity switch. The alarm contacts of these sensors were wired in series with the power supply to the hydrogen supply solenoids housed in the J-40 hydrogen supply module. An alarm condition or loss of power in any of these sensors would result in a loss of power to the hydrogen supply solenoids de-energizing them in a normally closed state. Before hydrogen flow could be re-activated, the alarm condition had to clear, and an operator was required to manually re-energize the system.

Fuel Cell Operation:

Installation

The fuel cell was installed in building 401 on March 6, 2002. The fuel cell was monitored for several days. Fluctuations in the hydrogen flow requirements of the fuel cell necessitated change out of the low-pressure regulator in favor of a higher volume low-pressure regulator. An additional modification that had to be made was the addition of an exhaust system to the output vents of the SR-72. The SR-72's exhaust is warm humidified air. Size constraints of the fuel cell room required the fuel cell be installed 8 inches from a wall. This resulted in a large amount of input air being taken from the exhaust stream. The system began to overheat, reducing the amount of fuel cell power being produced. The exhaust vents of the 6 SR-12s comprising the SR-72 were connected in series and ducted into the existing room air exhaust ductwork, Figure 13. This resulted in a significant decrease in room air temperature and mixing of the input and exhaust air streams, and a return to rated SR-72 power output.

Figure 13

Installed Cost:

The SR-72 was installed in mid February. The costs of the initial installation of the hydrogen distribution storage and distribution system, the preparation of the fuel cell room and the costs associated with a consulting Professional Engineer are listed below:

Hydrogen & Distribution System: $15203.00
Fuel Cell Room Preparation (Mechanical and Electrical): $5461.00
Labor for Consulting Professional Engineer: $1650.00
Total Installed Cost: $22,314.00

Operation:

The SR-72 fuel cell system ran for over 8760 hours of operation throughout the course of the project. The data collected is invaluable and has already resulted in product improvements. This section references Appendix A: Performance Data, and will discuss the project performance through the course of the one year test.

The system ran without difficulty throughout the first month- April. However, there were difficulties regarding hydrogen delivery logistics. This process was streamlined through cooperation with National Guard personnel to ensure a reliable delivery schedule when people were on site. Additionally, email notification was added to the data logging system. When a bank of hydrogen cylinders was exhausted, a pressure switch sent a signal to the on-site computer which would initiate an email notifying the hydrogen delivery personnel. This notification method streamlined the hydrogen delivery system and resulted increased system availability.

In June, the availability of the SR-72 decreased sharply. This was directly attributable to increased temperatures in the fuel cell room. The Series 250 fuel cell cartridges used in the SR-72 had an upper operating temperature of approximately 35 degrees C. In June, the temperature in the room was routinely well above 35ºC resulting in decreased power output of the fuel cell cartridges. As the power output of the cartridges decreased, the DC Bus voltage would drop and the SR-72 inverter would trip off. While not a failure of the fuel cell itself to operate, it was a failure of the fuel cell to meet the required load, and the targeted availability.

To address the high temperatures, it was necessary to install an air conditioner to maintain the temperature in the room below 35º C. As you can see from the data, the availability of the system in July is dramatically improved.

Fuel delivery logistics once again created a decrease in availability in November and December. This issue was once again addressed and availability increased.

Maintenance Log:

The number of site visits required for the duration of the project is listed below in Table 1. These visits correlate to the information given above that details the operation of the system throughout the course of the year.

Table 1: Maintenance Visits by Month to Geiger Field Installation		
Month	**Visits to Site**	**Percent Availability**
April	**3**	**88.31**
May	**1**	**97.22**
June	**2**	**94.93**
July	**2**	**93.70**
August	**1**	**99.29**
September	**2**	**99.53**
October	**1**	**97.02**
November	**2**	**90.92**
December	**3**	**90.50**
January	**2**	**95.25**
February	**2**	**95.48**
March	**2**	**82.71**

Data Acquisition:

Throughout the course of the test, there were intermittent losses of the data by the data acquisition system. This would necessitate reinitializing the data acquisition system. Whenever possible, we would confirm the fuel cell was operational and available to the load through on-site base personnel. When confirmation of system operation was obtained, these lapses did not count for or against the total system availability. Therefore, our reported availability for this test is conservative.

Site Restoration:

On March 29th, 2003, the one-year field trial was completed. The overall system availability exceeded 94%. Upon completion of the test, personnel from the 242nd were queried concerning their wishes for site restoration. It was requested to return the fuel cell room to storage location for cleaning supplies, and to install plumbing to allow for janitorial use.

Room Restoration:

The SR-72, the associated data acquisition sensors, safety sensors, electrical distribution, and hydrogen distribution equipment were removed from the room. The room was refinished and a new sink was installed.

Hydrogen Storage Restoration:

The base personnel requested that the hydrogen storage facility remain intact, as they would like it to serve as a greenhouse. The hydrogen piping running from the fuel cell room to the hydrogen storage shelter is in the process of being converted to a water supply system to the future greenhouse.

Lessons Learned:

The Geiger Field installation provided valuable experience and long term testing data. Running an SR-72 for a period of one year in a field installation allowed Avista Labs the opportunity to gain knowledge of NFPA Code, application limitations, and product improvements that would be necessary for future product designs.

Applications Engineering:

The installation of the system was directed by Avista Labs' applications engineering department. The installation work was subcontracted to local contractors. The design of the installation adhered to applicable codes and standards, see Appendix A, Table 2. A registered Professional Engineer was hired throughout the installation process to oversee and sign off on the safety of the hydrogen delivery system, the hydrogen storage system and the fuel cell installation. The Geiger Field installation increased familiarity with installation codes and standards and their applicability resulting in a more effective applications engineering department at Avista Labs and more knowledgeable facilities personnel at Geiger Field.

Product Engineering:

The Avista Labs SR-72 fuel cell utilized in the Geiger Field installation is an air-cooled system. Additional pumps, compressors, or humidification systems are not required. Being an air-cooled system, there is an upper limit to the operational temperature of the system. The SR-72 utilized an earlier version of Avista Labs' Series 250 Cartridge. This cartridge had an upper temperature limitation of approximately 35ºC. Several times the temperature at the installation at Geiger Field exceeded the upper temperature limit of the 250 Series Cartridge. When operated at temperatures above it's operational range, a cartridge will produce less power, eventually dry out and be taken off line. Even though the fuel cell system will continue to operate and provide power, that total power output will be reduced.

Throughout the course of the test, cartridges that had tripped off line were returned to Avista Labs for testing purposes, it was found the majority of cartridges returned for testing could be brought back up to power when rehydrated in the lab. This was useful in determining failure modes of the 250 Series cartridge.

Work had already been in progress to raise the upper operating temperature and the output power on the 250 Series Cartridge. The Geiger Field installation reinforced the value of this work and emphasized the importance of raising the upper limit on operating temperature. Fourteen months after the installation of the SR-72 at Geiger Field, the 250 Series cartridge will now produce rated power utilizing ambient air temperatures up to 45ºC. This is a 40% increase in the operating temperature range of this cartridge.

Marketing Focus:

The SR-72 utilized at Geiger Field was comprised of six SR-12 fuel cell systems. The output of these systems was then bussed together to a common battery bank, from that battery bank the power was fed into a 5kW inverter. The power was then fed into the customer's AC system. The Geiger Field installation exposed two very important limitations of this design philosophy.

First, while effective, this design was not efficient. The energy produced by the SR-12s was fed into a battery system, the battery system acted as a buffer. There was an efficiency loss associated, typically 25%, with the batteries. The power was fed to a 5kW inverter. There was an efficiency loss, approximately 15%, associated with converting from DC to AC power. The power was supplied to the customer's load on the AC distribution system. The overall efficiency of hydrogen to electricity out in this system was a little less than 30%. Today, our DC fuel cell systems achieve overall efficiency levels of 37% or more.

Secondly, the installation at Geiger Field showcased the costs associated with producing power for base load applications utilizing hydrogen. At the time of the installation, a commercial fuel reformer was not available. The cost of a prototype reformer was in excess of $50,000. Hydrogen gas in compressed cylinders was the most readily available cost-effective fuel solution for our system. The cost of power throughout the Geiger Field test was approximately $3.91/kWh. See Table 2 for an economic analysis of the cost of fuel cell power versus the standard cost of power to the Geiger Field installation.

Table 2: Economic Cost Comparisons	
Geiger Field Electricity Cost per kWh:	$.03185/kWh
KWh Provided by SR-72 throughout period:	6370.48 kWh
Cost of Hydrogen ($0.09/CUF) x H2 Consumed:	$26,737.25
Cost of Electricity per kWh:	$3.91/kWh
Electrical Savings to Geiger Field versus Grid	$202.89 - $26,737.25 = - $26,534.36
Natural Gas Usage (assuming 29.31 therms/kWh)	6370.48 / 29.31 = 217.35 Therms
Natural Gas Cost	217.35 * $0.68 = $147.8
Savings, H2 fuel source verses Reformer System:	$50,000 - $26737.25 – $147.8 = **$23,114.95**

Clearly, the cost of power generated by the fuel cell using hydrogen fuel far exceeds the cost of electricity from the grid. Given the inefficiencies associated with converting fuel cell power from DC power to AC power, the current state of the hydrogen infrastructure and the low cost of AC power from Utilities in the Northwest utilizing hydrogen fueled PEM fuel cells to provide base load AC power is not cost effective. It is important to note the logic behind not utilizing a natural gas reformer for this project. At the time of the installation of this system, prototype reformers were priced in excess of $50,000. It would not have been possible to offset the capitol costs of a fuel cell reformer. Based on the metrics of this project, a savings was realized by using a hydrogen fuel source.

There currently exists a substantial hydrogen infrastructure in the form of compressed cylinders. Hydrogen gas in compressed cylinders has worldwide availability. Competing with base load AC power with compressed hydrogen is not economically viable. However, utilizing compressed hydrogen and PEM fuel cells to compete with existing methodologies in the premium power market for backup or intermittent power is economically viable.

Conclusion:

The Geiger Field installation provided invaluable long-term testing data, increased the knowledge base of the applications engineering team, as well as Air National Guard personnel, and provided a testing platform to illustrate necessary product improvements. The CERL program provides a platform to demonstrate PEM technology and prove the reliability and viability of this technology.

It has also played a helpful role in the design of next-generation products with fewer performance limitations and higher operating efficiencies.

Appendix A:

Performance Data:

Month	Outages (hours)	Monthly Time in Period (hrs)	System Availability	Fuel Consumed (liters)	kWh	Avg. Inside Temp (C)	vg Outside Temp (C)	Avg Inside RH	vg Outside RH	Avg. Power	Efficiency	Capacity Factor
March	1.50	60	97.47%	54,785.80	36.46	32.39	11.73	16.41	57.32	0.61	23.93%	0.20
April	81.33	720	88.31%	720,005.13	551.24	26.91	12.11	22.82	70.58	0.77	27.53%	0.26
May	16.03	744	97.22%	748,250.82	596.63	24.47	14.07	43.47	70.24	0.80	28.67%	0.27
June	30.37	720	94.93%	788,384.85	616.64	27.45	20.71	40.31	48.50	0.86	28.13%	0.29
July	46.60	744	93.70%	870,463.84	656.21	17.86	25.43	53.46	35.28	0.88	27.11%	0.29
August	5.23	744	99.29%	916,306.51	689.10	13.56	22.85	60.87	36.53	0.93	27.04%	0.31
September	2.40	720	99.53%	659,157.83	493.84	14.04	18.98	58.83	43.75	0.69	26.94%	0.23
October	21.80	744	97.02%	846,894.26	629.08	15.17	10.62	45.39	48.74	0.85	26.71%	0.28
November	64.30	720	90.92%	709,258.45	517.32	19.20	5.90	36.33	71.27	0.72	26.23%	0.24
December	69.33	744	90.50%	637,255.78	470.78	21.93	3.89	29.71	80.11	0.63	26.57%	0.21
January	23.80	744	95.25%	569,362.21	404.86	15.68	4.76	51.22	84.82	0.54	25.57%	0.18
February	24.43	672	95.48%	572,509.94	468.11	18.25	4.88	35.64	66.34	0.70	29.40%	0.23
March	55.07	696	82.71%	314,743.90	240.21	20.30	7.02	34.68	67.35	0.35	27.44%	0.12
Totals	442	8772	94.89%	8,407,379.32	6,370.48	21.30	14.63	40.76	56.23	0.77	26.89%	0.26

* System unavailability not directly attributable to a fuel cell failing to provide rated power does not count for / against System Availability percentages.

Table 2: Referenced Standards:

NFPA 50A – Standard for Gaseous Hydrogen Systems at Consumer Sites.
NFPA 853 – Standard for the Installation of Stationary Fuel Cell Power Plants.
CGA G-5.4 – Standard for Hydrogen Piping Systems at Consumer Locations.
CGA G-5.5 – Hydrogen Vent Systems.
NFPA Article 70 – National Electric Code.
ANSI Z21.83 – Fuel Cell Power Plants.